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STUDIES ON THE SELF-PURIFICATION OF STREAMS.[1]

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The extensive sanitary investigations that are being carried out by the United States Public Health Service upon the Potomac River under the direction of Surg. Hugh S. Cumming and upon the Ohio River under the direction of Passed Asst. Surg. Wade H. Frost offer an unprecedented opportunity for the collection and study of certain basic data necessary to a general discussion of the principles of the self-purification of streams. From a strictly sanitary viewpoint a study of this phenomenon centers about the life of pathogenic bacteria in water, while from the point of view of nuisance it is concerned with the biological oxidation of organic matter. The present discussion is confined to the latter aspect of the problem.

The self-purification of streams is in no way a unique or remarkable process. It is essentially like the oxidation and destruction of organic matter by the soil. In the case of a polluted stream, however, ideal conditions for oxidation may exist, and these, assisted by other factors, such as dilution and sedimentation, combine to produce such improvement that the phenomenon has ever been regarded as one peculiar to itself.

The reactions involved in this process are essentially biochemical reactions. For their occurrence it is necessary to bring together oxidizable organic matter, oxygen, and oxidizing bacteria. The first and last are necessarily present in polluted waters, so that questions of stream purification and prevention of nuisance reduce to one of oxygen supply.

Atmospheric oxygen tends to re-enter the water in proportion as the oxygen content of the water is lowered by the oxidation of organic matter. The intensity of the driving force of re-aeration is a direct function of the lowering of this oxygen content. It is at a maximum in a completely deoxygenated water, and this is, therefore, the condition of maximum oxidizing work in any stream. This condition, however, is also one of maximum nuisance and is not to be tolerated. Such an anaerobic stream gives off foul odors and is black and unsightly in appearance.

It becomes a matter of some importance, therefore, to determine the minimum value which the dissolved oxygen of the stream may reach before conditions approach the nuisance stage. This point practically fixes the capacity of the stream in question to care for pollution. The lower the permissible oxygen concentration the greater the proportion of the initial dissolved oxygen of the water available for the oxidizing reaction, and the greater the capacity of the stream to absorb oxygen from the atmosphere.

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[1] Condensed from a paper read before the American Chemical Society, at Cincinnati, Ohio, September, 1913.

Upon this question of permissible oxygen reduction, there are many diverse opinions and very little real knowledge. This point must be definitely determined before any general discussion of the capacity of streams for self-purification becomes possible.

The second and most important factor in self-purification is the degree of agitation of the stream. The rate of re-aeration of water depends not only upon the oxygen concentration existing at the time but upon the vertical distribution of that concentration. Assume, for example, that the water is uniformly mixed and quiescent. Absorption at the surface leads to a downward diffusion which in time establishes a gradiant ranging from essential saturation in the upper film to the initial concentration at some point below. The diffusion process becomes slower as the curve of distribution of oxygen becomes flatter. In practice, quiescent water, even though it start with zero oxygen concentration at all points, will, except in shallow layers, come to a condition of practical equilibrium with very low average oxygen concentration. Beyond this point the diffusion process is exceedingly slow. Mixing of the water, after such a condition has become established, reestablishes the even distribution and allows the absorption to proceed toward a new condition of equilibrium. It is apparent, therefore, that, as conditions depart more and more from the condition of complete quiescence, the rate of reaeration is increased accordingly. The departures from quiescence may be definitely stated, and are more easily conceived, as the average time between uniform mixings. This form of expression is used, not only because it gives a workable statement of the degree of agitation in a stream, but because such a time factor appears in any formula for re-aeration derived from the laws of solubility and of diffusion. Such a formula was developed by Col. William M. Black, Corps of Engineers, United States Army, and the writer in an investigation of the pollution of New York Harbor. In that case it was possible to determine the average time between mixings from a study of the mixing effect of winds, vessels, and tidal currents. The re-aeration calculated from this theoretical formula, using the determined time factors, was in close agreement with the actual values found during the subsequent year and thus gave satisfactory confirmation of the accuracy of the method. With the deep and relatively quiescent waters of New York Harbor reæration was found to be almost a negligible factor. The capacity of such a body of water to oxidize pollution is practically limited by the amount of available oxygen brought in from the ocean with each tide.

In rivers the conditions are reversed. The initial volume of available oxygen is small compared with the total capacity of the stream to oxidize pollution. Re-aeration in rivers is the chief factor. The time between mixings instead of being measured in hours is probably measured in minutes, and its actual determination from direct observations can not be made with even workable precision. It becomes necessary, therefore, to reverse our process of reasoning, to learn by suitable methods the actual extent of re-aeration, and thence to derive the time factor in the original aeration formula. This factor will vary with the depth, character of the river bed, and rapidity of flow. It will differ, therefore, for various rivers and for various sections of each river, but should be similar for similar types of stream. If it can be determined for a sufficiently large number of typical stream stretches, it may be possible to deduce general formulas which will be applicable to other streams of similar type. It should then be possible to estimate the capacity of a given river to dispose of pollution without objectionable results, or, conversely, the effect of any stated pollution upon a river of given type.

The actual rate of re-aeration in a polluted stream can not, unfortunately, be determined directly. In spite of re-aeration a stream at any given point may be losing oxygen, or in oxygen equilibrium, since at all times the biochemical reaction tending to reduce the oxygen is opposed to the actual re-aeration. It is necessary, therefore, to develop suitable chemical methods for the separation of these opposing tendencies.

Consider first an ideal situation with two sampling stations on the stream between which stations there is no increment either to the pollution or to the volume of the stream. These conditions can not, as a rule, be obtained and it is necessary to make suitable correction for the interference of additional pollution or additional dilution. The oxidizing reaction has been studied in the laboratory sufficiently to show that it follows a fairly definite course and, like all biochemical reactions, is essentially monomolecular in its order. This means that it proceeds at a constant rate or velocity so that the concentration of oxidizible material decreases as a logarithmic function of the time. A sample of the water from the upper station is submitted to study for the determination of three things: The available oxygen which it contains; the total amount of oxygen which will be required for the completion of the oxidizing reaction, known as the oxygen demand; and the velocity with which that reaction proceeds. The sample from the lower station is submitted to the same examination. Since any loss of available oxygen must, by oxidation, give rise to an equivalent loss in the oxygen demand, the difference of these two terms remains constant throughout the course of the reaction in the absence of re-aeration. Any increase in dissolved oxygen at the lower station over the value calculated from the results of examinations at the upper station is therefore due to aeration. Correction for additional pollution or dilution between the stations is made by means of the velocity of reaction determinations. From the determination at the upper station and the known time required for water to pass from one station to the other the concentration of reacting substance at the lower station is calculated. With increasing dilution the concentration is decreased, while with increasing pollution it is increased. Any change in the concentration, calculated from an assumed constant velocity of reaction, indicates an equivalent change in dilution or pollution between these stations. It is obvious that these two factors are opposed to one another in a plus and minus sense and that if the added water were of the same character relative to its pollution as the water under investigation, the correction factor would disappear. In brief, from the known constant velocity of reaction, stated in terms of physical chemistry, are determined changes in the concentration of the reacting substances, namely, pollution.

The actual laboratory technique of these determinations is simple. The usual dissolved oxygen determinations are made upon a freshly collected sample; a second sample is incubated at 20° C. and a dissolved oxygen determination made upon it at the end of any convenient period, usually 24 or 48 hours. The differences between these two results is the oxidation that has taken place in the interval. Knowing the form of the reaction curve, one computes from this, first, the velocity coefficient of the reaction and then, by exterpolation to a very long time, the total oxygen demand of the polluting organic matter. These two determinations at each station furnish the required data. There are, however, many points that require special attention. It is necessary in the first place to secure an adequate sample of the entire cross section of a stream. This involves the careful selection of sample stations and the sampling of a stream at various points in the cross section both vertically and horizontally. It is desirable in the second place to select stretches involving a minimum correction for additional pollution or dilution and it is quite necessary finally to consider the effect of sedimentation. This can only be arrived at by a study of the surface of the river bottom. A special apparatus is necessary for the withdrawal of the surface deposit from a given area of bottom between stations from time to time. A new reaction velocity must be determined for this deposited material and suitable correction made to the average findings in the water above for the period between the two bottom mud surveys. Finally the temperature of the river is not that at which the incubations are made. The temperature coefficient of the reaction must be known and suitable correction applied.

Studies of this character are being made a part of both river investigations alluded to and it is to be hoped as a result of these studies that sanitarians will be in a position to discuss with much more assurance than at present the general principles which underlie the phenomenon of the self-purification of streams.